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OPERATION SUN BEAM, SHOTS LITTLE FELLER I AND II, JOHNIE BOY, AND SMALL BOY

Project Officers Report—Project 2.4

Integrated Gamma Dose Measurements

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NOTICE:

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This project was conducted (1) to provide gamma support measurements for other projects, (2) to determine the integrated gamma dose as a function of distance, and (3) to verify the changes in gamma measurements caused by neutron interactions with the shields, soil, and the gamma detectors.

To accomplish these objectives, the gamma dose was measured by film badges, glass micro-dosimeters, formic acid chemical dosimeters, cobalt glass, and thermoluminescent dosimeters.

The neutron interactions with the gamma detectors and their accompanying shields agreed with theoretical calculations. The experimental data for the capture-gamma contribution from the soil agreed with theoretical calculations.

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FOREWORD

Classified material has been removed in order to make the information available on an unclassified, open publication basis, to any interested parties. The effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is either currently classified as Restricted Data or Formerly Restricted Data under the provisions of the Atomic Energy Act of 1954 (as amended), or is National Security Information, or has been determined to be critical military information which could reveal system or equipment vulnerabilities and is, therefore, not appropriate for open publication.

The Defense Nuclear Agency (DNA) believes that though all classified material has been deleted, the report accurately portrays the contents of the original. DNA also believes that the deleted material is of little or no significance to studies into the amounts, or types, of radiation received by any individuals during the atmospheric nuclear test program.

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OPERATION SUN BEAM

SHOTS LITTLE FELLER I AND II,
JOHNIE BOY, AND SMALL BOY

PROJECT OFFICERS REPORT—PROJECT 2.4

INTEGRATED GAMMA DOSE MEASUREMENTS

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ABSTRACT

This project was conducted (1) to provide gamma support measurements for other projects, (2) to determine the integrated gamma dose as a function of distance, and (3) to verify the changes in gamma measurements, caused by neutron interactions with the shields, soil, and the gamma detectors.

To accomplish these objectives, the gamma dose was measured by film badges, glass microdosimeters, formic acid chemical dosimeters, cobalt glass, and thermoluminescent dosimeters.

Project 2.4 provided gamma support measurements for other projects for Shots Small Boy, Little Feller II, and Johnie Boy.

Gamma measurements, as a function of distance from ground zero, were made from 450 to 4,000 feet for Shot Small Boy, and from 30 to 2,400 feet for Shots Little Feller I and II, and Johnie Boy. Measured values of gamma dose were higher by at least a factor of 2 than predicted doses for Shots Small Boy, and Little Fellers I and II.

Theoretical calculations of neutron interactions with blast shields and soil were verified.

In addition, an experiment was performed to determine the initial radiation-measuring capabilities of the U. S. Army Quartz-Fiber Dosimeter (IM-93/UD) and to compare it to its Canadian counterpart, the IM-5013.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The objectives of Project 2.4 were (1) to provide gamma support measurements for other projects, (2) to determine the integrated gamma dose as a function of distance, and (3) to verify the changes in gamma measurements, caused by neutron interactions with the shields, soil, and the gamma detectors.

1.2 BACKGROUND

Although the major portion of the energy release of a nuclear detonation in the atmosphere is in the form of blast and thermal radiation, the integrated nuclear radiation yield is an important factor in the employment of nuclear devices. In fact, in the case of very-low-yield devices, the nuclear radiation yield is considered to be the controlling criteria for safe employment (Reference 1), since the effective radius of the blast and thermal effects may be less than that of the nuclear radiation effects. In addition, shielding calculations of ordnance equipment, structures, and fortifications are dependent upon knowledge of the radiation characteristics of tactical nuclear weapons.

Although many techniques have been used to measure gamma radiation, the film badge was used at all operations where gamma measurements were made (References 2 through 28). In conjunction with film badge measurements, a number of different film holders were used to provide energy independence and electronic equilibrium. Among the more common types of holders were the National Bureau of Standards (NBS) holder, the Los Alamos aluminum-wood holder, and the Edgerton, Germeshausen and Grier (EG&G) modified NBS holder.

Additionally, various glass dosimeter systems were employed to measure gamma radiation. The DT-60/PD (Personnel Dosimeter) was used at various times before Operation Plumbbob (References 6, 21, and 29). At Operations Plumbbob and Hardtack, silver phosphate glass microdosimeters were introduced and used with some success (References 23, 25, and 27).

Then, too, a number of chemical dosimeter systems, including chloroform (References 11, 15, 16, and 21), tetrachloroethylene, single and double phase, (References 11, 15, 21, 23, 25, and 30), and trichloroethylene (Reference 30), were used with varying degrees of success.

However, the results obtained from all these systems were questioned because of the neutron response of the detector itself, as well as the interaction of neutrons with the shields used to protect the detectors from blast and thermal radiation. In many cases, this interaction produced sufficient secondary gamma rays to cause an appreciable increase in the total dose measured by the detector.

Previous measurements of gamma radiation emitted by a low-yield surface detonation were restricted primarily to measurements made at the Nevada Test Site during the surface shot (Shot Sugar), Operation Jangle (References 7 and 31). The dose-rate measurements were restricted to a time resolution of 0.1 second and recorded data up to 24 hours. Because of recovery problems, the film used for total gamma dose remained in a fall-out-contaminated area up to 50 hours after detonation. Thus, the gamma measurements reported were a combination of initial and residual radiation.

Since Operation Plumbbob, recovery techniques have improved, and information is available to correct the gamma results obtained by detectors which are also neutron sensitive.

The Nuclear Defense Laboratory (NDL) obtained the direct interaction correction factors for most dosimeter films (Reference 32), while the neutron interaction factors for glass micro-dosimeters have been evaluated by other investigators (References 33 and 34). Also, the correction factors for the secondary gamma radiation produced by neutron interaction in the shields and soil were theoretically obtained (References 35 and 36). However, it remains to determine experimentally this effect.

It was for this purpose, as well as to determine accurately the integrated gamma dose obtained from a low-yield land surface detonation, that this experiment was directed.

1.3 THEORY

The gamma component from a nuclear detonation is generally divided into two categories, initial and residual. Arbitrarily, the initial gamma radiation will be considered to be that which is emitted during the first minute after the explosion. This initial radiation results from many nuclear reactions and effects, of which there are four that predominate. Three of these reactions and effects have been extensively discussed (References 37 and 38), while the fourth one, the gamma arising from neutron interactions with the environment, has only recently been given a closer examination (Reference 36).

These four major contributors to initial gamma radiation are:

1. The gamma rays produced by the fission process and by neutron interactions with the materials in the weapon. These rays are emitted within the first few microseconds and are known as prompt or instantaneous gamma rays. This radiation is heavily absorbed in the bomb materials and casing which still surround the nuclear fuel.

2. High energy (4.5 to 10.8 Mev) photons emitted from the interaction of thermal and fast neutrons with nitrogen in the air and the nitrogen in the weapon's high explosives. This radiation occurs from a millisecond to a quarter of a second after detonation. The fast neutron interaction is particularly important in the case of boosted devices.

3. Fission-product gamma rays emitted from the fireball

and cloud. These gamma rays have a mean energy of about 1 Mev and are responsible for almost all the initial gamma dose after 1/4 second.

4. The gamma dose arising from neutron interactions with the environment other than air. This gamma dose can be produced by various neutron interactions but one predominates; the (n,γ) interaction with the ground. This capture-gamma dose is a minor contributor to the overall gamma radiation at the greater distances, but at the closer stations it may be the major contributor. This radiation is considered to occur in the same time frame as the nitrogen capture gamma.

The residual gamma radiation is defined as the radiation emitted after one minute following the detonation. This radiation can result from deposited bomb residues and from activity induced by neutrons captured by various elements present in the earth or in substances in the vicinity of the detonation. A complete discussion of induced activities in soil may be found in Reference 39.

The gamma-ray exposure dose is dependent upon distance from the point of detonation. There is the general decrease with distance due to the geometrical spreading of the radiation over larger and larger areas as it travels away from the point of detonation. The dose received is thus said to be governed by the inverse square law. Also, the intensity of the dose is diminished because of absorption and scattering of the rays by the intervening atmosphere. If the burst is close to the surface of the ground, the presence of dust and debris will cause a decrease in the expected initial gamma dose at any particular location.

CHAPTER 2

PROCEDURE

2.1 SHOT PARTICIPATION

Project 2.4 participated in four shots during this operation (Table 2.1). The primary objective of the participation in Shot Small Boy was that of support for the Program 6 projects (Electromagnetic). However, the primary objective of the remaining three events was to document the gamma dose versus ground range.

2.2 OPERATIONS

All the Project 2.4 gamma detectors, with the exception of one station at Shot Small Boy, were placed in blast shields and attached with wire rope clamps to the wire rope or manila rope recovery lines of Project 2.3 (Neutron Flux Measurements). The one Small Boy station that was not attached to the recovery cables was in a low-overpressure area and was therefore taped to a wooden stake. Clear line of sight to the point of detonation was insured by elevating each station slightly with saw horses and sand bags. Recovery of the detectors, made in conjunction with Project 2.3, was effected by using a tractor or truck to pull the recovery line out of the surrounding high radiation field. The detectors were then detached from the recovery line and transported to NDL. The dose to which the glass and chemical dosimeters were exposed was determined at NDL, while the exposed film was sent to the

U. S. Army Signal Corps Research and Development Laboratory (SRDL) for processing and interpretation. The Naval Research Laboratory (NRL) determined the dose that the thermoluminescent dosimeters received.

Support for other projects and the station locations are presented in subsequent sections.

2.2.1 Shot Small Boy. Table 2.2 gives the various stations and the types of dosimetry used to measure the gamma dose versus distance. Figure 2.1 shows the relative positions of these stations.

Experiments to determine the effect of shields upon the gamma detectors were conducted at stations 512.06a and 512.07. These experiments consisted of exposing several shielded and unshielded detectors at each location. In addition, one detector at each of the above two stations was positioned over 24- by 24- by 5-inch lead shields in an attempt to ascertain the capture gamma contribution from the soil. Table 2.3 gives the detector array exposed at stations 512.06a and 512.07.

Support was provided for Program 6 projects by supplying approximately 125 detectors which were installed at various locations within their bunkers. An additional 100 detectors were supplied to Project 7.2 (Experimental Confirmation of Theoretical Development on Radiological Armor) for external and internal gamma measurements in connection with shielding studies of several M-48 tanks and a Radiation Protective Pod (RPP). One set of detectors was also supplied to Project 7.8 (Arming and Fuzing Component Test) dose inside a missile component.

2.2.2 Shot Little Feller II. Table 2.4 gives the various stations and the types of dosimetry used. Figure 2.2 shows the relative positions of the stations.

In addition, 25 detectors were supplied to Project 1.1 (Airblast Measurements from Small Devices). These detectors were placed in tanks and on a balloon line. Installation and recovery were effected by Project 1.1 personnel.

Project 2.20 (Transit Radiation Dose Rate) was supplied with 50 film badges that were used in studies of the transient gamma dose.

Appendix B contains a comparison of U.S. and Canadian dosimeters exposed during Little Feller II.

2.2.3 Shot Little Feller I. Project 2.4 participation consisted of instrumenting four lines of stations as shown in Figure 2.3. Table 2.5 contains all pertinent station information.

2.2.4. Shot Johnie Boy. Project 2.4 participation in Shot Johnie Boy consisted of a line of stations from 90 to 3,000 feet at an azimuth of 188 degrees. Table 2.6 contains all station information. Figure 2.4 shows the relative positions of the stations.

In addition, 58 film badges were supplied to Project 2.20 for transient gamma-dose measurements. Installation and recovery of these detectors were effected by Project 2.20 personnel.

2.3 INSTRUMENTATION

The integrated gamma dose (i.e. the initial plus the residual up to the time of recovery) was measured by using dosimetric film-badges, glass microdosimeters, oxygen-saturated formic acid dosimeters, manganese-activated calcium-fluoride thermoluminescent dosimeters, and cobalt-activated borosilicate-glass dosimeters.

2.3.1 Film Detectors. The gamma film dosimeters employed were similar to those used at past weapon tests. These dosimeters consisted of a NBS film holder loaded with two dental-size dosimeter film packets. The NBS holder (Reference 40) consists of a bakelite container with an 8.25-mm wall thickness covered with layers of 1.07 mm of tin and 0.30 mm of lead. A lead strip approximately 0.75 mm thick is wrapped around the outer edge of the holder to cover the seam. The holder was placed in a plastic cigarette case for protection from dust and moisture in the field.

The film packets used were the Dupont SX-231 packet, containing Emulsions 508, 510, and 1290, and the Eastman Kodak packet containing Emulsion 649-0. This combination of emulsions covers the dose range from 0.1 to 7×10^4 r. Table 2.7 gives the sensitivity ranges of the various dosimeter films exposed.

Since film sensitivity is affected by environment and manufacture, each batch was calibrated at the same time that the experimental gamma exposures were made. This was accomplished by calibration of the film at the test site just prior to shot time. The control, calibration, and experimental films were developed at the same time and their densities measured. The films were processed for 5 minutes at $20.80 \pm 0.20^\circ C$ with Kodak liquid X-ray developer. The density of the experimental film was then converted to dose by comparing it to the film that had been exposed to calibrated amounts of Co^{60} gamma radiation.

Neutrons will directly interact with the film, and thus yield readings that are higher than the true gamma response. Correction factors for the effect of neutrons were determined and were applied to the film data when the neutron spectrum and integrated flux were known. Table 2.8 lists data on film sensitivity to neutrons (References 32 and 41).

2.3.2 Glass Microdosimeters. The glass microdosimeters used were precision glass cylinders of silver-activated phosphate glass, 1-mm diameter and 6 mm long, manufactured by Bausch and Lomb Company. The basis of this system provides for the creation of new, stable luminescence centers in the glass rods by the action of ionizing radiation. The irradiated rods are evaluated by measuring their luminescence under ultra-violet radiation. Although the glass rods are energy dependent for energies below 100 kev, shields have been designed to make the response of the dosimeter uniform for all energies (References 42 and 43). However, due to the short lead time as well as the economics involved, lead and teflon shields were used as a field expedient. The shields were composed of a tight fitting 2-mm-thick teflon tube into which 2 glass rods were inserted end to end; a 0.75-mm lead strip was then wrapped once around the teflon, and the edges of the lead were crimped shut. The lead suppresses the lower energy radiation sufficiently to keep the response linear above

115 kev. Below 115 kev the gamma radiation is attenuated excessively. The teflon tubing was added to establish electronic equilibrium.

The range of the microdosimeters is 10 to 10,000 rads (Reference 44). With appropriate heating and readout techniques (Reference 45), the range can be extended to approximately 10^6 rads. The glass rods were calibrated at NDL and the Nevada Test Site. The calibration of the rods consisted of exposing them to known doses of radiation from either a 280- or 100-curie Co^{60} source. A calibration curve was then constructed by a plot of the difference in fluorescence between exposed and nonexposed rods versus dose. The cobalt sources were calibrated with standard Victoreen ion chambers that had been checked against dosimeters calibrated by NBS. The fluorescence of the exposed rods was measured with a Turner Model 110 Fluorometer and a Bausch and Lomb Microdosimeter Reader modified by the Electronics Branch of NDL in accordance with specifications determined by Oak Ridge National Laboratory (ORNL).

Corrections for fast and thermal neutron interactions with the glass rods were made according to data obtained from References 33 and 34 and are listed in Table 2.8.

2.3.3 Cobalt-Activated Borosilicate Glass. These dosimeters are glass plates 15 by 6 by 1.5 mm manufactured by Bausch and Lomb Company. The glass plates operate on the principle that exposure to ionizing radiation produces a pronounced darkening effect (Reference 44). The change in optical density measured at 390 mμ gives direct dose readings when compared to calibrated glass plates. The recommended range of the dosimeters is from 10^4 to 10^8 rads.

Calibration of the glass plates with a 10-curie Co^{60} source was done on the day of the shot to eliminate corrections for fading. A Perkin-Elmer Spectracord Model 4000A was used to measure the optical density of the exposed plates.

The neutron sensitivity of these dosimeter plates is not fully known at the present time. Preliminary work at the Sandia Pulse Reactor Facility (SPRF) has been done on the fast neutron response (Reference 41). More experimentation must be accomplished to obtain the neutron sensitivity corrections over a wide spectrum of energies.

2.3.4 Formic Acid Dosimeter. The formic acid dosimeter is composed of an oxygen-saturated aqueous solution of 0.01 normal formic acid and 0.001 normal sulfuric acid. When this solution is exposed to ionizing radiation, hydrogen, hydrogen peroxide, and carbon dioxide are the major products produced.

To determine the dose in a mixed neutron and gamma field the following equation is applicable.

$$A_t = D_\gamma A_\gamma + D_n A_n \qquad (2.1)$$

Where: A_t = total quantity of product A formed, moles/liter

D_γ = total gamma dose, rads

D_n = total neutron dose, rads

A_γ = yield of A, by gamma, moles/liter-rad

A_n = yield of A, by neutrons, moles/liter-rad

Therefore, if the amount of one product, A_t, and the neutron dose, D_n are measured, the gamma dose, D_γ, can be calculated, since A_γ and A_n for hydrogen and hydrogen peroxide are known from the literature (References 46, 47, and 48).

In practice, both hydrogen and hydrogen peroxide yields were determined. The gamma dose was calculated from the following equations; neutron dose was provided by Project 2.3.

$$D_\gamma = \frac{[H_2] - D_n\,(H_2)_n}{(H_2)_\gamma} \qquad (2.2)$$

$$D_\gamma = \frac{[H_2O_2] - D_n\,(H_2O_2)_n}{(H_2O_2)_\gamma} \qquad (2.3)$$

Where: D_γ = total integrated gamma dose, rads

$[H_2]$ = total yield of hydrogen, moles/liter

D_n = total neutron dose, rads

$(H_2)_n$ = yield of H_2 by neutrons, moles/liter-rad

$(H_2)_\gamma$ = yield of H_2 by gamma, moles/liter-rad

$[H_2O_2]$ = total yield of H_2O_2, moles/liter

$(H_2O_2)_n$ = yield of H_2O_2 by neutrons, moles/liter-rad

$(H_2O_2)_\gamma$ = yield of H_2O_2 by gamma, moles/liter-rad

A simultaneous solution of Equations 2.2 and 2.3 will yield both the gamma dose and neutron dose.

Hydrogen was separated from the solutions with a Van Slyke gas extraction apparatus and then quantitatively determined by a gas chromatographic technique using a molecular sieve column with purified air as the carrier gas (Reference 49). Hydrogen peroxide content was quantitatively determined by the spectrophotometric method described in Reference 50 with a Perkin-Elmer 4000A Spectrophotometer to measure the absorption peak at 350 mμ.

The solutions were exposed in transparent quartz ampules with a capacity of 6 to 7 ml. They were sealed by means of a vacuum O-ring and a standard taper joint.

2.3.5 Calcium-Fluoride Thermoluminescent Dosimeter. The managanese-activated CaF_2 thermoluminescent dosimeter is based upon the emission of light upon heating CaF_2 phosphors which have been previously excited by exposure to radiation. The radiation produces free electrons and holes; some of the electrons are trapped in the holes or in other inperfections. When the phosphor is heated, the charge carriers are expelled from the traps, and light is emitted upon their return to their normal positions. The dose is determined by plotting the luminescence of the exposed phosphors versus temperature at a constant heating rate and then comparing the area under the curve to similiar plots of calibrated dosimeters.

The rate independence of the dosimeter was verified to 7,000 r/min. Although the dosimeters are energy dependent, the use of appropriate shields made them independent of energy from 40 kev to 1.2 Mev (References 51 and 43). Work is presently being conducted on the energy dependence for energies greater than 1.2 Mev.

The neutron sensitivity has not been fully ascertained for this system; however, preliminary work at the Sandia Pulse Reactor Facility has been done on the fast and thermal neutron response (Reference 41). Additional experimentation must be conducted to determine the neutron sensitivity over a wide spectrum of energies. Earlier dosimeters were approximately the size of a pocket watch; the present dosimeter is a cylinder 1mm in diameter and 12mm long. These dosimeters were exposed in groups of five; the groups were wrapped with tin foil to achieve energy independence, and then covered with black electrical tape.

Since there is some fading of these dosimeters with time, they were flown from NTS to NRL as soon as possible after detonation. The dosimeters were prepared, calibrated, and read at NRL.

2.3.6 Shields. Two types of shields were used to protect the gamma detectors from blast, missile, and thermal-radiation damage. The first type of shield was a standard 3-inch diameter, 4-inch-long, steel pipe nipple, capped at both ends with standard black malleable iron caps. An eyebolt was attached to one of the caps so that connection could be made to the early recovery cables of Project 2.3. The other type of shield was a 3-inch diameter, 4-inch-long, laminated nylon pipe. The pipes were closed at each end with a screw-type nylon plug. Wall thickness of the nylon shield was approximately 1.25 cm. One plug had an eyebolt inserted so that connection could be made to the recovery cables.

To protect the gamma detectors from direct thermal-neutron interactions, sheets of Li^6 metal 2 mm thick were used. The 2-mm Li^6 shield will absorb over 99 percent of the thermal neutrons by a (n,α) reaction. The lithium sheets were enclosed in plastic under an atmosphere of helium to exclude oxygen, nitrogen, and water vapor, which react readily with lithium. The lithium was fitted to the inside of an ordinary beer can, which was placed inside an appropriate blast shield.

Examples of the five types of dosimeters and the various shields into which they were placed are shown in Figures 2.5 and 2.6.

2.4 DATA REQUIREMENTS

To accomplish project objectives, integrated gamma measurements were required at various distances from four nuclear detonations. It was necessary that the accompanying neutron radiations at each distance also be known, so that the recorded gamma doses could be corrected for neutron interactions. Neutron fluxes for these distances were obtained from Project 2.3.

Film, $AgPO_3$ glass microdosimeters, and cobalt-activated borosilicate-glass dosimeters, as previously described, were used to measure the integrated gamma dcse (i.e. the initial plus the residual gamma up to the time of recovery). In addition these systems were supplemented by using oxygen-saturated formic acid dosimeters and Mn-activated CaF_2 thermoluminescent dosimeters.

In order to correct the raw gamma data for neutron interactions and shield effects, the following expression was used:

$$D = (D_0 - N_{th}\ T\ B - N_f\ F - N_{th}\ S)\ A \qquad (2.4)$$

Where

D = final corrected gamma dose, r.

D_0 = uncorrected gamma dose, r.

N_{th} = external thermal neutron flux, n/cm^2.

T = thermal neutron correction factor, r/(n/cm^2).

B = thermal neutron enhancement factor.

N_f = external fast neutron flux, n/cm^2.

F = fast neutron correction factor, r/(n/cm^2).

S = shield correction factor, r/(n/cm^2).

A = shield attenuation factor.

The neutron correction factors, T and F can be calculated from the data given in Table 2.8. The fast neutron factor for the 649-0 film listed in the table is based on the fission-neutron spectrum of a pulsed reactor and may not be directly applicable to weapon test data. Therefore, until further work is performed, the 649-0 film data will not be corrected for fast neutron effects.

The shield correction factors (Reference 35) are listed in Table 2.9. As the distance from ground zero increases, the gamma spectrum hardens (References 38 and 52), and the attenuation factor A would be expected to decrease. Therefore, Table 2.9 shows A for two different distances from ground zero.

The thermal-neutron flux inside the nylon shields was found to be approximately 2.2 times higher than the thermal-neutron flux outside the shields. Therefore, a neutron enhancement factor B, had to be used to take into account the increased thermal flux inside the shields. There was no detectable difference between the fast-neutron flux inside and outside the nylon shields. Therefore, the increase in thermal flux is probably due to thermalization of the epicadmium neutrons, which were not measured.

TABLE 2.1 PROJECT 2.4 SHOT PARTICIPATION

Date 1962	Shot Code Name	Height Above Ground	Relative Air Density ρ
		feet	
7 July	Little Feller II	3	0.78
11 July	Johnie Boy	-1.92	0.81
14 July	Small Boy	10	0.84
17 July	Little Feller I	3	0.79

TABLE 2.2 STATION LAYOUT AND DOSIMETRY FOR SHOT SMALL BOY

A Film Badge
B Glass Rods
C Cobalt Glass
D Thermoluminescent
E Formic Acid

Station Number	Distance from Ground Zero	Azimuth	Pipe Nipple	Pipe Nipple Plus Li^6	Plastic	Unshielded
	feet	degree				
512.02	100	S 73°W		ABC	ABCE	
512.03	150	S 73°W		ABCD	ABCE	
512.04	250	S 73°W		ABC	ABCE	
512.05	450	S 73°W		ABCD	ABCE	
512.05a	625	S 73°W		ABCD	ABCE	
512.06	708	S 73°W		ABCD	ABCE	
512.06a	900	S 73°W	ABCDE	ABCD	ABCE	ABCD
512.07	1200	S 73°W	ABCDE	ABCD	ABCE	ABCD
512.09	250	N 43°E			ABC	
512.10	625	N 43°E			ABC	
512.11	1600	N 43°E			ABC	
512.12	4000	N 43°E			ABC	
512.13	625	N 16°W			ABC	
512.14	1600	N 16°W			ABC	
512.15	4000	N 16°W			ABC	
5-603	9800	N 43°E				AB[a]

[a] not attached to recovery cables

TABLE 2.3 LAYOUT FOR STATION 512.07[a]

A Film Badge
B Glass Rods
C Cobalt Glass
D Thermoluminescent
E Formic Acid

Detector	Pipe Nipple	Pipe Nipple Plus Li^6	Plastic Shield	Plastic Plus Li^6	Unshielded
1	ABCD	ABCD			
2	BCE				
3					
4			ABCE		ABCD
5				ABC	
6					
7		ABCD[b]			

[a]Station 512.06a had an identical set-up.
[b]Positioned over lead shield

TABLE 2.4 STATION LAYOUT AND DOSIMETRY FOR SHOT LITTLE FELLER II

A	Film Badge	D	Thermoluminescent
B	Glass Rods	E	Formic Acid
C	Cobalt Glass		

Station Number	Radial Distance from GZ	Azimuth	Pipe Nipple	Pipe Nipple Plus Li^6	Plastic Shield
	feet	degree			
1805.01	30	N 70°W	ABC		
1805.02	90	N 70°W	ABC		
1805.04	300	N 70°W	ABC		
1805.05	900	N 70°W	ABC		
1805.06	1500	N 70°W	ABC		
1805.07	30	S 65°W	ABC		
1805.08	90	S 65°W	ABC		
1805.10	300	S 65°W	ABC		
1805.11	900	S 65°W	ABC		ABCE
1805.12	1500	S 65°W	ABC		
1805.13	15	S 20°W		ABC	
1805.14	30	S 20°W	ABC		
1805.15	60	S 20°W	ABC		
1805.16	90	S 20°W		ABC	ABCE
1805.17	150	S 20°W		ABC	
1805.17	150[a]	S 20°W		ABC	
1805.17	150[b]	S 20°W		ABCD	
1805.17	150[c]	S 20°W		ABC	
1805.17	150[d]	S 20°W		ABC	
1805.18	225	S 20°W		ABC	
1805.19	300	S 20°W		ABCD	
1805.20	600	S 20°W		ABC	
1805.21	900	S 24°W		ABC	
1805.22	1200	S 24°W	ABC		
1805.23	1500	S 24°W		ABC	
1805.24	1800	S 24°W		ABC	
1805.25	2100	S 24°W		ABC	
1805.26	2400	S 24°W		ABC	

[a] On pole 5 feet above ground level.
[b] On pole 10 feet above ground level.
[c] On pole 15 feet above ground level.
[d] On pole 20 feet above ground level.

TABLE 2.5 STATION LAYOUT AND DOSIMETRY FOR SHOT LITTLE FELLER I

A Film Badge C Cobalt Glass
B Glass Rods D Formic Acid

Station Number	Radial Distance from GZ	Azimuth	Pipe Nipple	Pipe Nipple Plus Li^6	Plastic Shield
	feet	degree			
1805.27	150	N 25° E	ABC		
1805.28	90	N 25° E	ABC		
1805.29	90	S 65° E	ABC		
1805.30	300	S 65° E		ABC	
1805.31	900	S 65° E		ABC	
1805.32	1500	S 65° E	ABC		
1805.33	90	S 65° E	ABC		
1805.34	150	S 65° E	ABC		
1805.35	300	S 65° E	ABC	ABC	
1805.36	900	S 65° E		ABC	
1805.37	1500	S 65° E	ABC		
1805.39	90	S 25° W	ABC		
1805.40	150	S 25° W		ABC	
1805.41	300	S 25° W		ABC	ABCD
1805.42	600	S 25° W		ABC	ABCD
1805.43	900	S 25° W		ABC	
1805.44	1200	S 25° W		ABC	
1805.45	1500	S 25° W		ABC	
1805.46	1800	S 25° W		ABC	
1805.47	2100	S 25° W		ABC	
1805.48	2400	S 25° W	ABC		
1805.49	90	S 65° E	ABC		
1805.50	300	S 65° E		ABC	
1805.51	900	S 65° E		ABC	
1805.52	1500	S 65° E	ABC		

TABLE 2.6 STATION LAYOUT AND DOSIMETRY FOR SHOT JOHNIE BOY

A Film Badge
B Glass Rods
C Cobalt Glass

Station Number	Radial Distance From GZ	Pipe Nipple	Pipe Nipple Plus Li[e]	Plastic Shield
	feet			
1	90		ABC	ABC
2	120		ABC	ABC
3	150		ABC	ABC
3	150[a]		ABC	
3	150[b]		ABC	
3	150[c]	ABC		
3	150[d]		ABC	
4	225		ABC	
5	300		ABC	
6	450		ABC	ABC
7	600		ABC	ABC
8	750		ABC	
9	900		ABC	
10	1200		ABC	
11	1500		ABC	
12	1800		ABC	
13	2100		ABC	
14	2400		ABC	
15	2700		ABC	
16	3000		ABC	

[a] On pole 5 feet above ground level.
[b] On pole 10 feet above ground level.
[c] On pole 15 feet above ground level.
[d] On pole 20 feet above ground level.

TABLE 2.7 SENSITIVITY RANGES OF DOSIMETRY FILM

Packet Type	Emulsion Number	Recommended Range
		r
Dupont SX-231	508	0.1 to 10
Dupont SX-231	510	10 to 35
Dupont SX-231	1290	35 to 2,500
Eastman Kodak	649-0	2,500 to 70,000

TABLE 2.8 NEUTRON SENSITIVITIES OF DOSIMETERS

Dosimeter	Thermal	Neutron Energy (Mev) 1	2	4	6	8	14
	$10^9 (n/cm^2)/r$	$10^9 (n/cm^2)/r$					
Emulsion 508	3.6±0.90	110	75	27	20	6.5	-
Emulsion 510	4.8±1.2	10	5.5	3.8	2.9	1.6	0.83
Emulsion 1290	4.9±1.0	18	12	5.5	4.0	2.5	1.2
Emulsion 649-0	40±20	2[a]	-	-	-	-	-
$AgPO_3$ Glass	3.0	60[a]	-	-	-	-	-
Cobalt Glass Plates	0.14[b]	\[c]	-	-	-	-	-
Thermoluminescent	5.0	5.7[a]	-	-	-	-	-

[a] Value is an average for neutrons whose thresholds are greater than 10 Mev.
[b] Unpublished data
[c] Estimated to be $5x10^{10}$

TABLE 2.9 SHIELD CORRECTION FACTORS.

Shield	S, Gamma Dose from (n,γ) reaction	B, Thermal Neutron Enhancement Factor	A, Attenuation Factor: 0 to 1500 feet from GZ	A, Attenuation Factor: Over 1500 feet from GZ
	10^{-10} $r/(n_{th}/cm^2)$			
Steel	3.4	1	1.25	1.15
Nylon	0.53	2.2	1.11	1.06

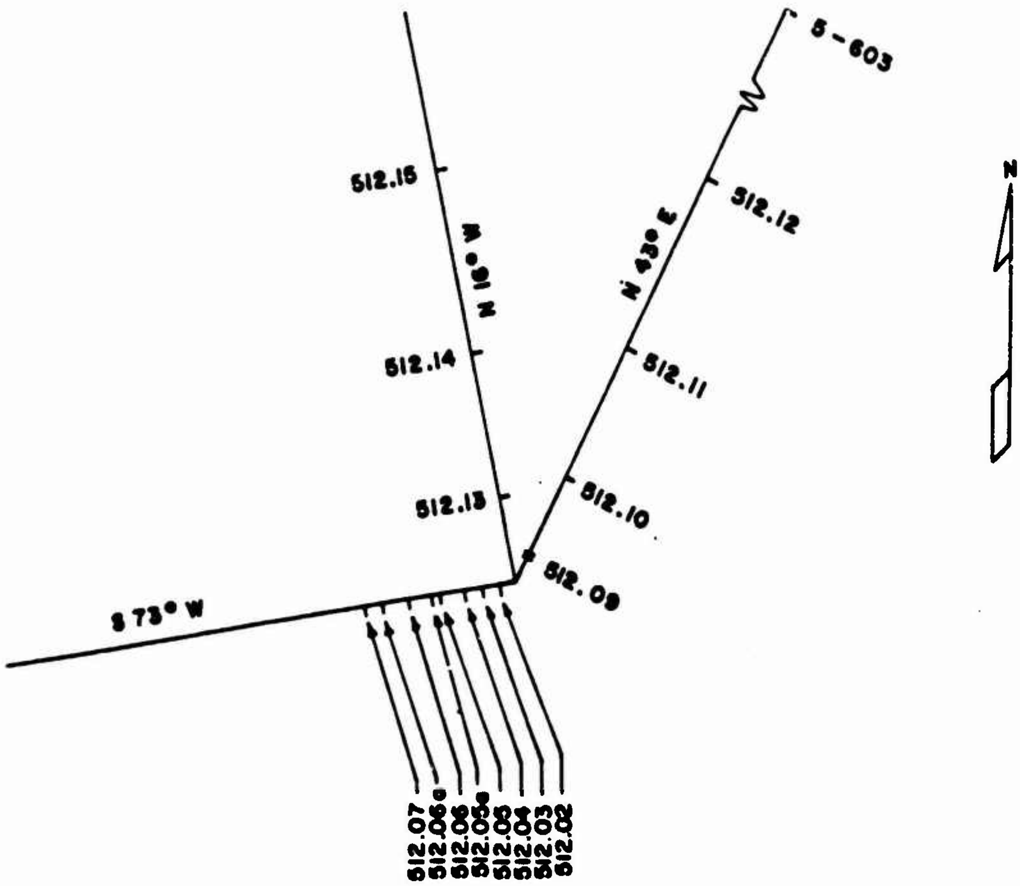

Figure 2.1 Station layout for Shot Small Boy.

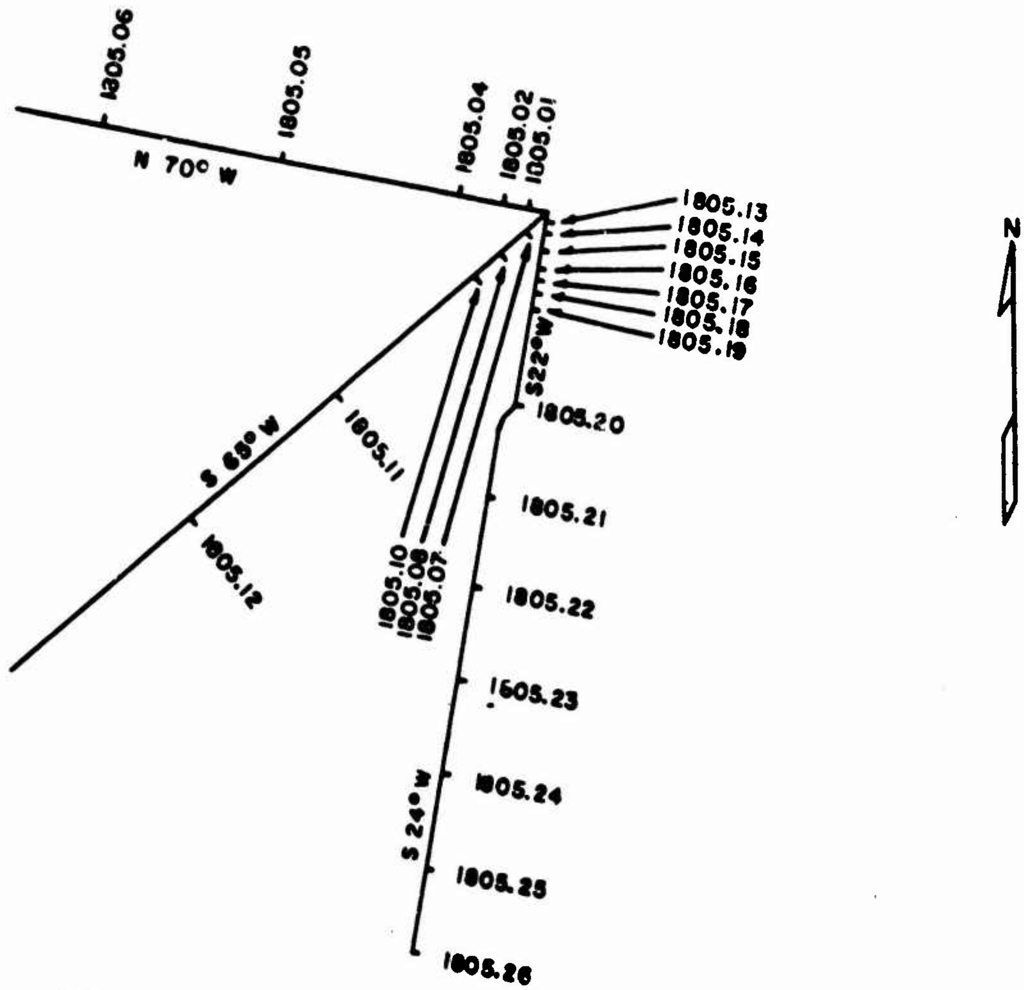

Figure 2.2 Station layout for Shot Little Feller II.

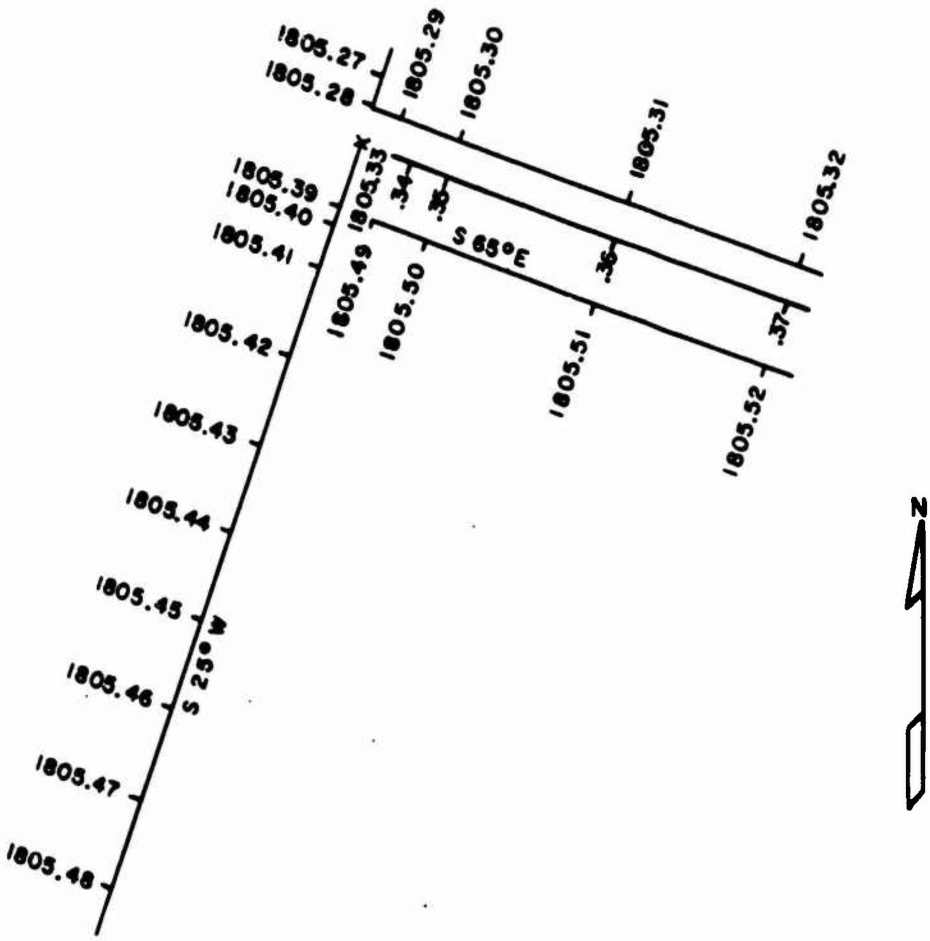

Figure 2.3 Station layout for Shot Little Feller I.

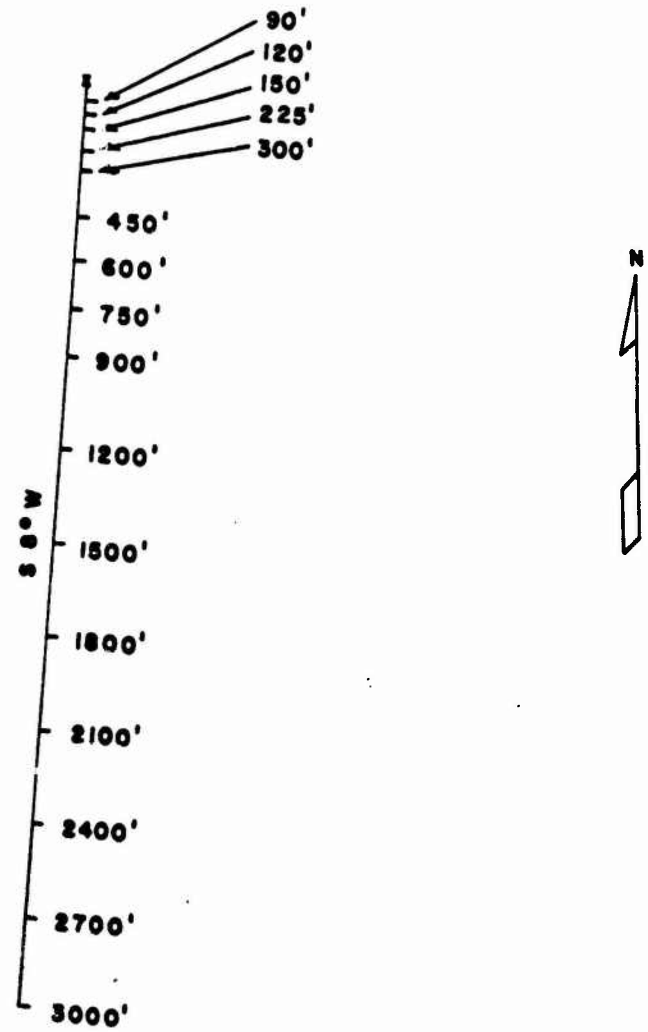

Figure 2.4 Station layout for Shot Johnie Boy.

Figure 2.5 Shields used to protect dosimeters. From left to right; nylon pipe, steel pipe nipple, and Li^6 thermal neutron shield. (NDL 23-458-2/A1-62)

Figure 2.6 Dosimeters used to measure gamma dose. From left to right, thermoluminescent dosimeter, formic acid in quartz bulb, $AgPO_3$ glass rods in lead and teflon shield, cobalt glass plates, and film in NBS holder. (NDL 23-458-5/A1-62)

CHAPTER 3

RESULTS

3.1 GAMMA DOSES FOR SHOT SMALL BOY

Table 3.1 shows the gamma data for Shot Small Boy. All the values in Table 3.1 have been corrected for neutron and shield effects. The step-by-step evaluation of neutron and shield effects on the dosimeters of a typical station is given in Appendix A. All gamma detectors were recovered except those at Stations 512.02, 512.03, 512.04, and 512.09, which were destroyed by the blast.

Recovery of all detectors, except those located at Stations 512.10 and 512.13, was effected by H+1 hour. These stations were recovered by H+24 hours. There is a discrepency between the film data and the glass data at Station 5-603. Eight glass rods exposed at this station indicated a dose of less than however, the average dose on two pieces of film, was The dosimeters at this station were not shielded from the sun, and there was a 7-day waiting period between installation of the dosimeters and detonation of the device. This prolonged exposure may have been the cause of the variation in dose readings, since film is very sensitive to heat.

Plots of the gamma dose versus distance, and gamma dose times distance squared versus distance, are shown in Figures 3.1 and 3.2, respectively. The gamma values used for these plots are the corrected averages of the film, $AgPO_3$ glass, and cobalt glass data.

The data obtained from the dosimeters placed at Stations 512.06a and 512.07 are presented in Table 3.2.

3.2 GAMMA DOSES FOR SHOT LITTLE FELLER II.

Table 3.3 lists the gamma data for Shot Little Feller II. All the gamma detectors were recovered by H+1 hour except those at Stations 1805.07 and 1805.13, which were destroyed by the blast. At Stations 1805.17c and 1805.19, thermoluminescent dosimeters were exposed and yielded doses of

respectively. Gamma dose versus distance, and gamma dose times distance squared versus distance, are plotted in Figures 3.3 and 3.4, respectively. The doses for these figures are the corrected averages of the film, $AgPO_3$ glass, and cobalt glass-plate readings. The curves are drawn only thru the Li^6 shielded stations on the main line.

3.3 GAMMA DOSES FOR SHOT LITTLE FELLER I.

Table 3.4 lists the gamma data for Shot Little Feller I. All gamma detectors were recovered from this shot by H+3 hours. The distances from ground zero of the various stations as given in Table 3.4 do not agree with the intended distances as given in Table 2.5. The reason for this is that the detonation occurred at Nevada State coordinates of N 859,072.57, E 601,837.89 instead of the intended coordinates N 859,076.12 and E 601,880.48.

This new ground zero is 42.74 feet from the intended ground zero at an azmiuth of 265° 14' from Grid North.

Gamma dose, and gamma dose times distance squared, are plotted versus distance from ground zero in Figures 3.5 and 3.6, respectively. The gamma values represent corrected averages of the film, $AgPO_3$ glass, and cobalt glass measured doses. The curves are drawn only thru the Li^6 shielded stations on the main line.

3.4 GAMMA DOSES FOR SHOT JOHNIE BOY

The gamma doses from Shot Johnie Boy are given in Table 3.5. The stations were all recovered by H+1 hour, with the exception of the nylon shields at Stations 1, 2, and 3 which were not recovered.

Gamma dose versus distance, and gamma dose times distance squared versus distance are plotted in Figures 3.7 and 3.8, respectively. Again, the corrected averages of the film, $AgPO_3$ glass, and cobalt glass measured doses were used for these figures.

Pages 47 through 59
were deleted.

CHAPTER 4

DISCUSSION

4.1 GAMMA DOSE AS A FUNCTION OF DISTANCE

Analysis of the residual radiation contours obtained by Project 2.8 indicates that in no instance could the residual field have contributed more than 1 percent of the dose recorded, and hence, the data in Figures 3.1 thru 3.8 represent initial gamma dose.

For the four shots, the dose-times-distance-squared values beyond 500 feet approximated straight lines. The shapes of these curves at distances less than 500 feet are difficult to determine. Some of the gamma data for these close-in stations came from cobalt plates that were not shielded with Li^6 and, therefore, are suspect. However, the Shot Johnie Boy curve displays a well-defined hump at approximately 200 feet. Since all the Shot Johnie Boy detectors, with the exception of the 90-foot station, were shielded with Li^6, it can be concluded that the hump in the curve is real.

The symmetry of the gamma field for Shot Small Boy is shown by the data from the 625-, 1,600-, and 4,000-foot stations on the various lines. The gamma doses at the same distances for the different radial lines are randomly scattered and agreed within experimental error. Thus, it can be concluded from the gamma data that Shot Small Boy was a symmetrical device. Similar comparisons were made of the gamma doses on the various instrumented radial lines from Shots Little Feller I and Little Feller II.

4.2 CORRELATION WITH PREVIOUS TEST DATA

Plots of gamma dose versus distance and gamma dose times distance squared versus distance for Shots Small Boy, Little Feller I and II, and Johnie Boy are presented in Figures 4.1 and 4.2, respectively. For these figures the gamma dose has been scaled to a yield of 1 kt and a relative air density of unity. Figure 4.2 also contains predicted gamma doses calculated with the use of the following expression (Reference 52):

$$\frac{D_\gamma R^2}{W h_{eff}} = (1.93 \times 10^9) \exp\left(-\frac{\rho R}{324}\right)$$

Where:

D_γ = total initial gamma dose, r

R = distance from detonation, yards

W = weapon yield, kt

h_{eff} = effective hydrodynamic scaling factor, which is essentially 1 for yields less than 10 kt

ρ = relative air density

This equation describes the curve which best fits the points of the experimental values for initial gamma dose-per-unit yield times distance squared versus distance from previous surface bursts of low-and intermediate-yield weapons. As can be seen from Figure 4.2 the slopes of the curves for the four shots at distances greater than 500 feet are similar to the predicted slope, but, with the exception of Johnie Boy, the curves lie above the predicted curve. The measured doses are higher than the predicted values but fall within the limits of the prediction method. Johnie Boy cannot be compared to any previous data, as it was the first time gamma was measured from a shot of this type.

A comparison of gamma doses from the main lines of Little Feller I and II with Shot Fig, Operation Hardtack, is shown in Figure 4.3. The gamma data for this plot were scaled to a relative air density of 0.9. Figure 4.3 shows that there is very little difference between the gamma doses from the two Little Feller Shots, but there is a large difference between the combined Little Feller data and Shot Fig. The Little Feller doses are higher by a factor of approximately 2 from those of Fig at distances greater than 500 feet.

4.3 EFFECT OF SHIELDS ON GAMMA DOSE

The doses measured by the various detectors simultaneously exposed in the steel and nylon shields are compared in Tables 4.1 and 4.2. A statistical evaluation of the gamma doses presented in Table 4.1 using an anlaysis of variance shows that the doses of the dosimeters exposed in the steel shields agree within ± 8 percent of the doses in the nylon shields. For this comparison, only the averages of the film and $AgPO_3$ glass dosimeters were used. The gamma doses measured by cobalt glass were omitted, since their response to thermal neutrons is not precisely known.

At two stations for Shot Small Boy, an unshielded dosimeter packet, as well as several shielded packets, were exposed. The results of these exposures are shown in Table 4.2. An indication of the reliability of the method used to reduce the data from shielded stations can be obtained from Table 4.2 by noting the agreement between the shielded and unshielded results. The only large discrepancy is the unshielded cobalt plate data. Since the cobalt plates were not shielded with Li^6, the results are approximations dependent upon the thermal neutron flux used to calculate the thermal neutron interaction contributions. Figure 4.4 shows station 512.06a as instrumented in the field (station 512.07 had an identical set-up). Note that the thermal neutron detector is not at the exact position that the unshielded gamma packet was located, and it is likely that this difference in location resulted in a difference in thermal neutron flux level. Due to this probable descrepancy in thermal neutron flux, the cobalt plate data in Table 4.2 is suspect. Therefore, it would appear from considerations of the final shielded and unshielded film and $AgPO_3$ glass data that the method used to handle the shielded data is reliable.

At all the shots except Little Feller I, some close-in stations were not recovered because of failure of the shields. The steel pipe nipples appeared to hold up better than the nylon shields; however, for very-high-overpressure areas, a new shield should be designed.

4.4 EFFECT OF SOIL ON GAMMA DOSE

In an attempt to ascertain the capture gamma contribution from the soil, one detector at each of two stations (Shot Small Boy) was positioned over a 24- by 24- by 5-inch lead shield; the difference between the free-field dose and that measured over the lead shield was due to the gamma from the soil. For these measurements, a steel pipe nipple containing Li^6 was used to house the detectors. In both cases, the dosimeters on the lead shields received a dose less than that recorded in the free field. These differences, as well as those predicted by the method given in Reference 36, are shown in Table 4.3.

The fact that there is only a small difference between the predicted and experimental dose is encouraging, since the reliability of the prediction method was considered good only to ±40 percent.

4.5 DATA RELIABILITY

Four main sources of error must be considered in an attempt to evaluate the total error involved in this experiment; (1) inherent uncertainties in the individual dosimeters, (2) unknown effect of environment, (3) uncertainties in the neutron data needed for the neutron interaction corrections, and (4) uncertainties of the correction factors.

Using an analysis of variance for the film and the $AgPO_3$ glass data presented in Table 4.1, the experimental error is calculated to be ±32 percent. This means that the mean value of the dose, as measured by film and $AgPO_3$ glass, is within ±32 percent of the true value. The data from Table 4.1 is a cross section of the total collected gamma data from the 4 shots and, as such, is considered representative of the total data. It is assumed that the error calculated for Table 4.1 is therefore applicable to the total gamma data.

At Station 1805.35 (100 yards from ground zero) at Shot Little Feller II, six sets of detectors were exposed to obtain an estimate of the precision of the measurements. The film averaged standard deviation of $AgPO_3$ glass

The dose at this station was too low for the cobalt plates to measure.

4.6 GAMMA DETECTOR SYSTEMS

When the three main gamma measurement systems (film, $AgPO_3$ glass, and cobalt glass plates) were used with Li^6 shields, agreement was obtained within experimental error. However, where Li^6 shields were omitted, the cobalt plate data was unreliable. This was due to the high thermal neutron sensitivity of the cobalt glass and the inherent difficulties in making appropriate corrections.

In those cases where manganese-activated CaF_2 thermoluminescent dosimeters were exposed, the measured dose was generally lower by a factor of approximately 3 when compared to the corresponding readings of the three main systems. One of the likely causes of this variance between the thermoluminescent and other dosimeters is dose rate dependence. This thermoluminescent system has been investigated only to a gamma flux of 120 r/sec, which is considerably lower than the 10^9 to 10^{11} r/sec expected at field tests. Experimental work on dose rate dependence of the thermoluminescent system must be undertaken to determine the absolute cause of the variance.

The formic acid dosimeters yielded no useable gamma data.

Work recently performed (Reference 54) has shown that formic acid is highly dose-rate dependent and, therefore, would not have been expected to function in these high dose-rate conditions.

Pages 68 through 72 were deleted.

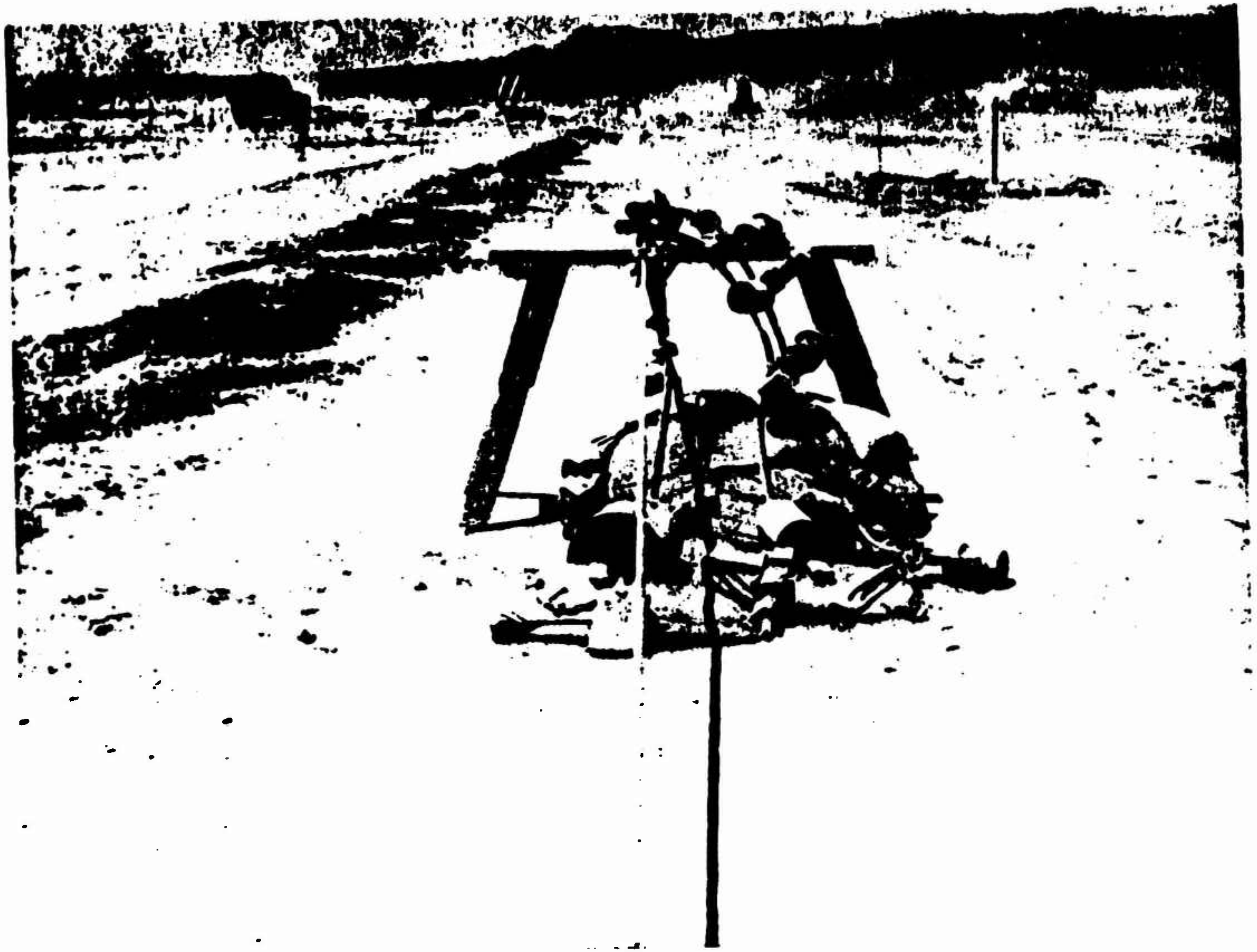

Figure 4.4 Instrumented field array at Station 512.06a, Shot Small Boy. (NDL photo)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Project 2.4 was able to measure gamma doses from 10 to 2×10^6 r over distances that ranged from 30 to 4,000 feet from ground zero.

The doses from Shots Small Boy, Little Feller I, and Little Feller II were within experimental error of those predicted by an AFSWP-1100 (Reference 52) prediction method.

The neutron interactions with the gamma detectors and their accompanying shields agreed with theoretical calculations.

The experimental data for the capture-gamma contribution from the soil agreed with theoretical calculations.

5.2 RECOMMENDATIONS

Future work is needed to determine precisely the shape of the gamma curve at distances less than 500 feet from ground zero. If the gamma dose can be defined at these close-in distances, it may be possible to extrapolate to the case of the weapon itself. This data would be of great value in examining gamma transport theories.

Continuing experimental work should be done on new gamma detection systems and on more accurate determinations of the neutron interactions with the present systems and on their dose rate dependence.

APPENDIX A

EXAMPLE OF EVALUATION OF NEUTRON AND SHIELD EFFECTS

In correcting the raw gamma data the following equation was used.

$$D = (D_0 - N_{th}\ T\ B - N_f F - N_{th}\ S)\ A$$

Where:

D = final corrected gamma dose, r.

D_0 = uncorrected gamma dose, r.

N_{th} = external thermal neutron flux, n/cm^2.

T = thermal neutron correction factor, $r/(n/cm^2)$.

B = thermal neutron enhancement factor.

N_f = external fast neutron flux, n/cm^2.

F = fast neutron correction factor, $r/(n/cm^2)$.

S = shield correction factor, $r/(n/cm^2)$.

A = shield attenuation factor.

In Table A.1 the values for the various terms from the correction equation are presented for two sets of shielded detectors which were exposed simulaneously at one station at Shot Small Boy.

Table A.2 presents the step-wise evaluation of the various corrections and the final corrected dose for the two sets of detectors in question.

TABLE A.1 NUMERICAL VALUES OF THE TERMS IN THE CORRECTION EQUATION

Dosimeters at station 512.07, Shot Small Boy

Symbol	Film-649-0	$AgPO_3$ Glass	Cobalt Plates
D_o (Steel)[a], r	23,000	23,000	25,000
D_o (Nylon)[b], r	25,000	27,700	160,000
N_{th}, n/cm^2	9.1×10^{12}	9.1×10^{12}	9.1×10^{12}
T, r/(n/cm^2)	2.5×10^{-11}	3.3×10^{-10}	7.1×10^{-9}
B(Steel)	1	1	1
B (Nylon)	2.2	2.2	2.2
N_f, n/cm^2	1.79×10^{13}	1.79×10^{13}	1.79×10^{13}
F, r/(n/cm^2	-	1.7×10^{-11}	-
S (Steel), r(n/cm^2)	3.4×10^{-10}	3.4×10^{-10}	3.4×10^{-10}
S (Nylon), r(n/cm^2)	5.3×10^{-11}	5.3×10^{-11}	5.3×10^{-11}

[a] Steel Shield with Li^6
[b] Nylon Shield without Li^6

Page 77 was deleted.

APPENDIX B

COMPARISON OF U. S. AND CANADIAN GAMMA DOSIMETERS

This appendix was prepared by Robert J. Smith.

B.1 INTRODUCTION

Operation Sun Beam afforded this project an opportunity to expose fifty IM-93/UD standard U. S. Army Quartz-Fiber Dosimeters during the Little Feller II event to obtain field performance data. As a comparison, fifty Canadian IM-5013/PD Quartz-Fibre Dosimeters, twelve DT-60A/PD Phosphate Glass Dosimeters, and fifteen Calcium Benzoate-Salicylic Acid Chemical Dosimeters were exposed at the same positions. The IM-93 has had a checkered history as a dosimeter. When exposed to a calibrated source of gamma rays, the IM-93 recorded gamma dosage within ±10 percent of the true dosage for midscale deflection. However, when exposed to the mixed radiation fields encountered at nuclear weapon tests, the IM-93 recorded dosage less than the gamma dose alone (References 55 and 56). Tompkins and Sasse (Reference 57) exposed IM-93 dosimeters to the mixed neutron and gamma radiation of the Lockheed Radiation Effects Reactor. Their results show that the IM-93 recorded a dose that was greater than the gamma dose alone. As long as the IM-93 remains a standard Army item, further investigations into its capabilities must be made.

B.2 EXPERIMENTAL

The Canadian and U. S. Army dosimeters were exposed near stations 1805.21, 1805.22, and 1805.23 along the S 24° W line. These stations were 300, 400, and 500 yards distant from the Little Feller II ground zero. Gamma and neutron measurements were made at these distances by Projects 2.3 and 2.4. The dosimeters were taped to a large cardboard sheet that was in turn nailed to three wooden stakes. The dosimeters were positioned so that they were approximately 3 feet above ground level. At 300 yards, twenty-five IM-93, twenty-five IM-5013, seven DT-60, and five chemical dosimeters were exposed; at 400 yards, twenty-five IM-93, twenty-five IM-5013, five DT-60, and five chemical dosimeters were exposed; and at 500 yards, five chemical dosimeters were exposed.

The 300- and 500-yard stations were recovered within 30 minutes after the detonation, while the 400-yard station remained in place until 24 hours had elapsed. All three stations were in the up-wind area.

The IM-93 and IM-5013 dosimeters were read in the field with the standard U. S. Army Quartz-Fiber Dosimeter Charger-Reader. The DT-60 and chemical dosimeters were returned to Canada for analysis.

B.3 RESULTS

The raw data for the IM-93 and IM-5013 dosimeters, as well as some statistical evaluation, are given in Table B.1. Table B.2 summarizes and compares these data with the free-field gamma and neutron results. The film and glass-rod gamma results have been corrected for neutron effects and shield attenuation. The average of the sum of these measurements is considered the standard gamma dose. The standard neutron dose has been calculated from neutron flux data by the single collision theory.

B.4 DISCUSSION

The DT-60 and chemical-dosimeter results are higher than the correct gamma results (film and glass rods). This is as it should be, since no neutron corrections have been made. However, since the DT-60 composition is very similar to the glass rod, corrections for neutron effects on the DT-60 can be estimated by use of the neutron correction factors for the glass rods. With these estimated corrections, the DT-60 results for 300 and 400 yards are 520 r and 205 r, respectively. No corrections have been attempted for the chemical dosimeter.

The precision of the IM-5013 results is excellent, while the precision of the IM-93 results is poor. Surprisingly, however, the accuracy of the IM-5013 is less than that for the IM-93 when compared to the corrected or true gamma values. The poor agreement, overall, between quartz-fiber dosimeter data and gamma measurements made by film or glass rods was expected from experience obtained at previous weapon tests and at reactors. Normally, the quartz-fiber gamma dosimeter, when exposed to a mixed gamma and neutron field, will record the gamma dose plus some contribution from the neutrons. Tompkins and Sasse found this to be true for the IM-93 when exposed to gamma and neutron radiation at a reactor. In this experiment, the gamma-to-neutron ratio was lowered with lead shielding to rule out the explanation that neutrons suppress the gamma-recording capability of the quartz-fiber dosimeters at weapon tests.

One of the differences between radiation from a reactor and from a weapon test experiment is the rate of delivery of the dose. A major portion of the radiation from a nuclear weapon is delivered in an incredibly short time, from milliseconds to microseconds.

B.5 CONCLUSION

From the results shown in this report, it is concluded that quartz-fiber dosimeters cannot be used to measure any radiation, much less gamma, in an initial radiation field. Dose-rate dependence is believed to be responsible for the low results.

Pages 83 through 95 were deleted.